Established 1845 SCIENTIFIC AMERICAN September 1972 Volume 227 Number 3

Communication

It is not only the essence of being human but also a vital property of life. Technological advances in communication shape society and make its members more interdependent

by John R. Pierce

Our existence depends on communication in more ways than one can easily enumerate. Without our initial backlog of genetic messages we would not be who we are, and without our internal communication system we could not continue to live and function as we do. Our internal communications are handled by a network with nervous and metabolic subsystems [see "Cellular Communication," by Gunther S. Stent, page 42]. Nerve impulses are like telephone calls that are switched to a particular recipient and heard nowhere else. Hormones are like messages addressed to individuals or groups but sent out broadcast; only those concerned need respond. Furthermore, certain cells in the body behave with seeming autonomy, seeking out invaders and destroying them. Indeed, the failure of these cells to destroy cancer cells has been attributed to a blockage of the mode of communication by which foreign or abnormal cells are recognized.

When we think of communication, however, we usually think of external communication, of those processes by which we communicate with others. Without external communication we might live, but we would be ignorant, lonely individuals. We would have neither the inspiration of accumulated skill and knowledge nor the support of a society. That society, which communication makes possible, supplies us with necessities we would otherwise have to obtain for ourselves. Moreover, communication with others conveys rewards far beyond the basic necessities of life.

Animals live without knowing how they live, and they communicate without knowing how they communicate. By and large, so do we. Unlike animals, however, we speculate about how we live and how we communicate. Our better brains and our unique means of communication—language—make such speculation possible. Occasionally we learn something incontrovertible, and such knowledge can be very powerful in our lives.

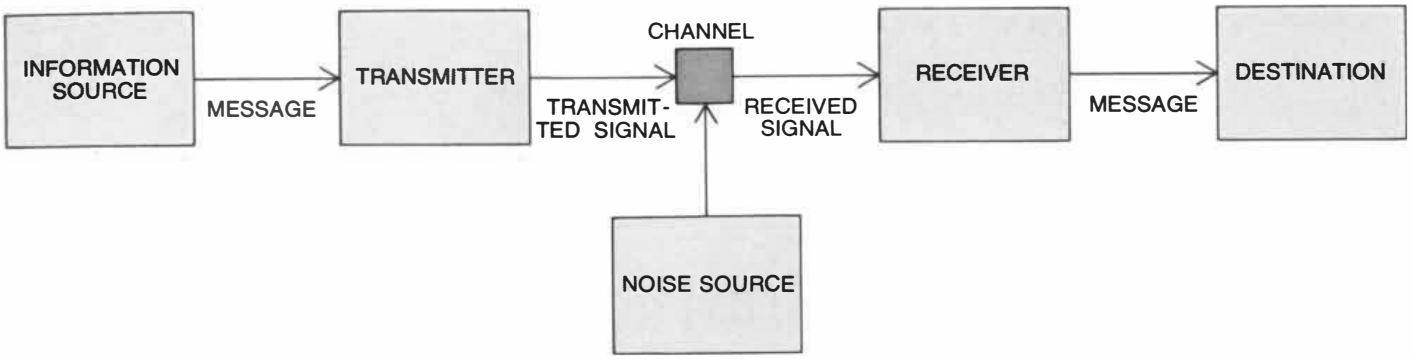
Our clearest and most fruitful knowledge is not knowledge of ourselves or of how we communicate. Rather it is knowledge of various physical and chemical processes. That knowledge has enabled us to make powerful tools that have changed our lives greatly. We understand these tools far better than we understand ourselves.

In part that is because the tools are simpler than we are. A television set, a computer or even a national communication network such as the telephone system is simpler than a human being. We also understand our tools better because those tools have been built according to our understanding. It is easier to understand a computer than it is to understand art or the weather because the man who built the computer wanted to build something that would work. In order to build something that would work he had to build something he could understand.

No one man understands all the devices in a big airplane, a tall building or a telephone system, but some men have at least a working knowledge of each. That is not true of man and his means of communication. We have learned some remarkable things, but chiefly we live and communicate not through our understanding of these processes but in spite of our ignorance concerning them.

In our puzzlement about man and his communication it is natural to turn for enlightenment to the sure knowledge and deep insight that we have concern-

ONE KIND OF COMMUNICATION is print. This page is reproduced from the type "form" shown in the photograph on the opposite page. The columns of type (and this caption) are set by Linotype. The headline ("Communication") is a copper photoengraving, and the subheading is type set by hand. These items and the incidental type at the top of the page are locked into position by a rectangular set of "bearers," which are beyond the margins of the picture. The complete form is used to make a nylon replica that is mounted on one cylinder of a high-speed rotary press and does the actual printing. Running at full speed, the press delivers 20,000 copies of SCIENTIFIC AMERICAN per hour. Photograph was made at The Lakeside Press, R. R. Donnelley & Sons Company in Chicago.



UNIVERSAL COMMUNICATION SYSTEM symbolically represented in this block diagram was originally proposed by Claude E. Shannon in his influential 1948 paper "The Mathematical Theory of Communication." The usefulness of Shannon's theory to the communication engineer is based in the broadest sense on the fact that it reduces any communication system, however complex, to a few essential elements. Modern communication theory is derived in large part from the ideas outlined by Shannon in his paper.

ing the nature, behavior and limitations of some of man's machines. Frequently it seems that what we have learned about machines should apply in some way to ourselves and our activities. We feel on occasion that the scales have fallen from our eyes and that the means for understanding are in our hands. At last we shall know.

In 1948 two publications created an intellectual stir about communication that has not yet subsided. These works were a paper titled "The Mathematical Theory of Communication," which Claude E. Shannon published in the July and October issues of the *Bell System Technical Journal*, and Norbert Wiener's book *Cybernetics: Control and Communication in the Animal and the Machine*. For the purposes of this discussion I should like to add to these two works a third: *Syntactic Structures*, published by Noam Chomsky in 1957.

Shannon's communication theory (also known as information theory) and Wiener's cybernetics created a broad and lasting interest and enthusiasm. In 1949 Shannon's paper was reprinted in book form together with exposition and comment by Warren Weaver. Weaver's contribution was based in part on an article by him in the July 1949 issue of *Scientific American*. These books alerted the scientific world. Conferences were held here and abroad. Scientists, shallow and profound, tried to extend the ideas of Shannon and Wiener to all aspects of life and art. I remember Shannon's telling me how he sat in a conference watching a man who spoke with his eyes turned toward the heavens, as if he were receiving divine revelation. Shannon was disappointed that he could not make any sense out of what the man was saying. Cybernetics and communication theory have been with us for nearly a quarter of a century. What have they taught us? I looked through the books to find out.

Shannon's "The Mathematical Theory of Communication" summarizes and clarifies the task of the communication engineer in a remarkable way. The system Shannon studied is a truly universal communication system. As shown in the first figure of his paper [*see illustration above*], it consists of an information source, a transmitter, a communication channel, a noise source, a receiver and a message destination.

In such a communication system the information source and the message destination are usually human beings. As an example, a human being may type a message consisting of the letters and spaces on the keyboard of a teletypewriter. The teletypewriter serves as a transmitter that encodes each character as a sequence of electrical pulses, which may be "on" or "off," "current" or "no current." These electrical pulses are transmitted by a pair of wires to another teletypewriter that acts as a receiver and prints out the letters and spaces, which are in turn read by the human being serving as the message destination.

As the pulses travel from the teletypewriter that serves as the transmitter to the teletypewriter that serves as the receiver, an intermittent connection or an extraneous current may alter or mutilate them so that the receiver teletypewriter prints out some wrong characters. Shannon sums up such alterations or mutilations of the signal by including a noise source in his diagram of the communication system. Ordinarily the signal is an electrical signal, and the noise is an unpredictable interfering signal that is added to the desired signal.

The noise can cause the received message to differ from the message the source wished to transmit. The greater the ratio of the power of the signal to the power of the noise is, that is, the greater the signal-to-noise ratio, the less effect the noise will have on the operation of the communication system.

This example of a communication system based on the use of teletypewriters is a very simple one. In contrast let us consider a voice communication system based on the automatic speaking machines known as vocoders. The transmitter part of such a system analyzes a speech signal and obtains data to control a speaking machine at the remote receiver. The control signals so obtained are the signals that are sent from the transmitter to the receiver. These control signals operate the distant speaking machine. Excessive noise in the transmission path may cause errors of articulation in the speech the message destination hears.

In this example we come on another concept introduced by Shannon. The vocoder and its control signals must be complex enough to produce speech that meets a fidelity criterion set by the message destination. If we fail to meet the fidelity criterion, the purposes of the communication system will not be fulfilled. If we produce better speech than is necessary, the system will be inefficient.

Thus Shannon's diagram of a communication system can apply to a system that is very complex indeed. Moreover, Shannon's theory can tell the communication engineer something meaningful and useful about any communication system. It gives him a measure of the commodity he is trying to transmit. That measure, a unit of uncertainty or choice, is called a bit. A bit (a contraction of "binary digit") is the uncertainty between "yes" or "no" or "heads" or "tails" when both are equally likely; it is the choice we exercise in choosing "left" or "right" most unpredictably (that is, with equal probability for each). The symbols 0 and 1 (that is, the digits of a binary

© 1972 SCIENTIFIC AMERICAN, INC

number) can specify yes or no, heads or tails, left or right.

Shannon showed how in principle to measure the information rate of a message source—a speaker, a person writing, the output of a television camera—in bits per message or bits per second. This quantity is called the entropy or entropy rate of the source.

Shannon also showed how to measure the capacity of a communication channel. Again the measure is bits per second. The entropy rates of different message sources vary widely. Studies conducted by Shannon show that the entropy of English text is probably about one bit per character. The entropy rate of speech is not known. Experiments with vocoders indicate that it is less than (and probably much less than) 1,000 bits per second; in contrast we routinely use a channel (the telephone) capable of transmitting 60,000 bits per second of high-quality speech. A channel capable of transmitting some 60 million bits per second is generally used in transmitting television pictures, but the entropy rate of the picture source must surely be far less than that.

One thing is clear: It is necessarily more costly to transmit a television picture than to transmit speech, and more costly to transmit speech than to transmit text. Transmitting a detailed picture, whatever its worth, is bound to be more than 1,000 times more costly than efficiently transmitting 1,000 words of text.

Shannon contributed a great deal in establishing the bit as a measure of the complexity of message sources and the capabilities of channels. In addition he proved an extraordinary theorem. He showed that if the entropy rate of a message source does not exceed the capacity of a communication channel, then in principle messages from the source can be transmitted over the channel with a vanishingly small probability of error. This can be achieved only by storing an exceedingly long stretch of message before transmitting it [see "Communication Channels," by Henri Busignies, page 98].

Shannon's communication theory has had two chief values. One is rather like the value of the law of conservation of energy. Shannon has made it possible for communication engineers to distinguish between what is possible and what is not possible. Communication theory has disposed of unworkable inventions that are akin to perpetual motion machines. It has directed the attention of engineers to real and soluble problems. It has given them a quantitative measure of the effectiveness of their systems. Shannon's work has also inspired the invention of many error-correcting codes, by means of which one can attain error-free transmission over noisy communication channels.

Information theory and coding theory are widely pursued areas of research. It is true that many real and significant problems seem too difficult to solve, and that many of the problems that are solved seem made up because they can be solved rather than because they are very significant. Nonetheless, communication theory as Shannon conceived it has enduring importance.

Shannon is an engaging and lucid writer. In his exposition of what he had done he used amusing as well as enlightening examples. One example was a message source in which the probability of the next letter depended on the preceding letters. Such a source produced "words" such as *grocid, pondenome, demonstures* and *deamy.* Shannon's choice of technical terms, on the other hand, was evocative as well as apt; it included *information, entropy, redundancy* and *equivocation.* Surely a theory that dealt with such wide-ranging concepts must have wide-ranging application.

So thought Weaver, as he expressed himself in "Recent Contributions to the Mathematical Theory of Communica-

CHANNEL	CHANNEL BANDWIDTH (HERTZ)	CHANNEL CAPACITY (BITS PER SECOND)
TELEPHONE WIRE (SPEECH)	3,000	60,000
AM RADIO	10,000	80,000
FM RADIO	200,000	250,000
HIGH-FIDELITY PHONOGRAPH OR TAPE	15,000	250,000
COMMERCIAL TELEVISION	6 MILLION	90 MILLION
MICROWAVE RELAY SYSTEM (1,200 TELEPHONE CHANNELS)	20 MILLION	72 MILLION
L-5 COAXIAL-CABLE SYSTEM (10,800 TELEPHONE CHANNELS)	57 MILLION	648 MILLION
PROPOSED MILLIMETER-WAVEGUIDE SYSTEM (250,000 TELEPHONE CHANNELS)	70 BILLION	15 BILLION
HYPOTHETICAL LASER SYSTEM	10 TRILLION	100 BILLION

CAPACITY OF VARIOUS COMMUNICATION CHANNELS can be measured according to Shannon's theory in bits per second, as indicated in the column at the extreme right in this chart. The numbers given for each entry are more or less rough estimates for a particular system (either currently in operation, proposed or merely envisioned); in many cases it is difficult to ascribe even an approximate value for capacity in bits per second to an analogue channel because of the variability of parameters such as signal-to-noise ratio.

tion," his part of the 1949 book. Weaver plausibly divided the problem of communication into three levels: (*A*) the technical problem: How accurately can the symbols of communication be transmitted? (*B*) the semantic problem: How precisely do the transmitted symbols convey the desired meaning? (*C*) the effectiveness problem: How effectively does the received meaning affect conduct in the desired way?

Weaver recognized that Shannon's work pertained to level *A*, but he argued persuasively that it overlapped and had significance for levels *B* and *C* as well. Weaver was intrigued by the idea of using the powerful body of probability theory involving Markoff processes in connection with both languages and semantic studies. Moreover, in pointing out the pertinence of information theory to cryptography, he argued that information theory "contributes to the problem of translation from one language to another."

This brings us to the fascinating story of machine translation. Since most of the details of the story are irrelevant to communication, I shall simply sketch the broad outlines. In brief, when simple machine "dictionary look-up" produced ambiguous, unreadable texts, the proponents of computer translation turned to grammar for a cure. They found that existing grammars were unhelpful. In fact, they found that no attainable grammar cured the persistent ills of machine translation: inaccuracy, ambiguity and unreadability. As Victor H. Yngve, once an associate of Chomsky's, wrote in 1964: "Work in mechanical translation has come up against a semantic barrier. ... We have come face to face with the realization that we will only have adequate mechanical translation when the machine can 'understand' what it is translating and this will be a very difficult task indeed.... 'Understand' is just what I mean.... Some of us are pressing forward undaunted."

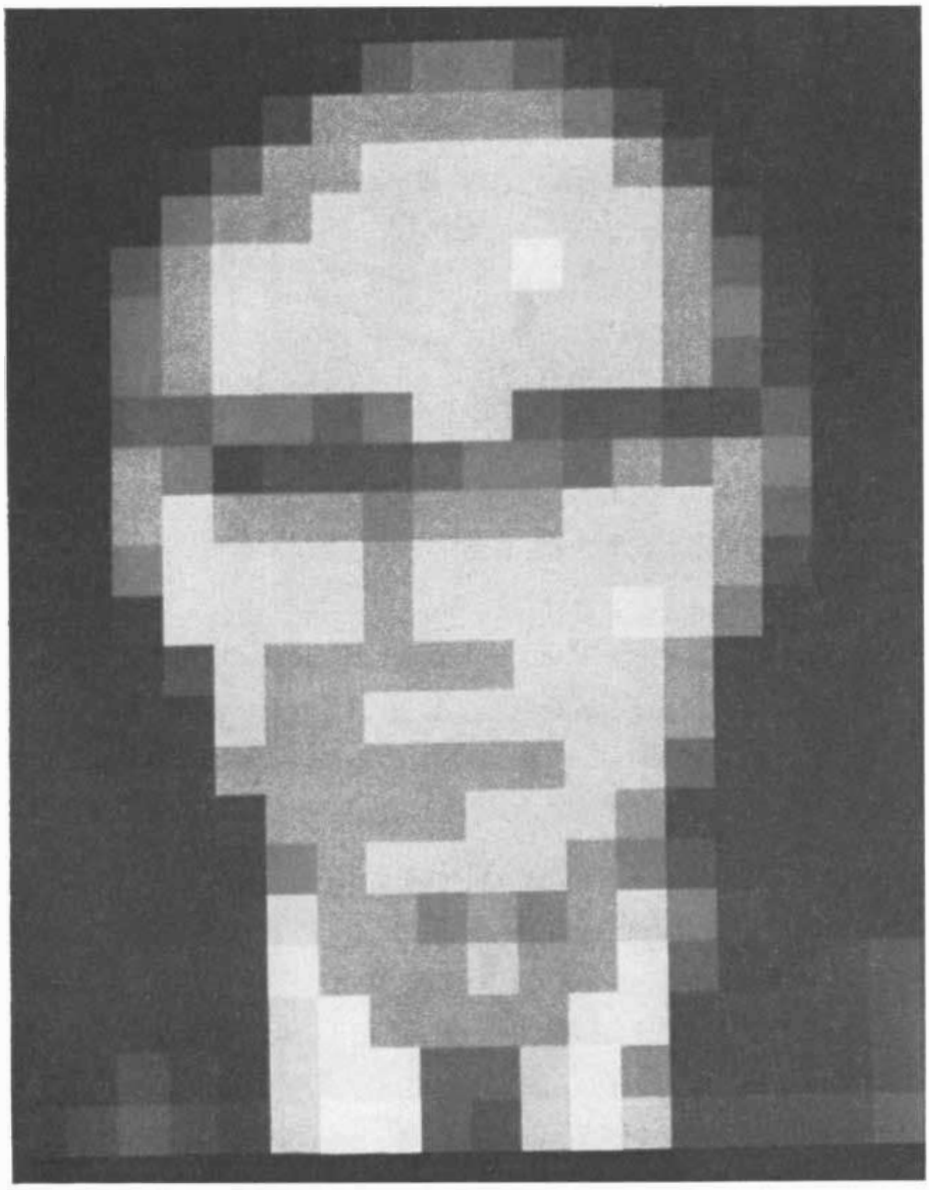
Both the Shannon-Weaver book and the search for a syntactical cure for the ills of machine translation led to a reexamination of syntax. In *Syntactic Structures* Chomsky sought an avenue toward a grammar of a language. Letting *L* stand for a language, he wrote: "The grammar of *L* will thus be a device that generates all of the grammatical sequences of *L* and none of the ungrammatical ones. One way to test the adequacy of a grammar proposed for *L* is to determine whether or not the sentences that it generates are actually grammatical, i.e., acceptable to a native speaker."

Chomsky rejected the Markoff process, which Weaver had mentioned, as being inappropriate and inadequate. Part of his argument was statistical. Although a statistical process can generate sentences, the likelihood that a sentence will occur has nothing to do with whether or not it is grammatical. Indeed, in 1939 Ernest Vincent Wright published a novel, *Gadsby,* in which the letter *e* simply does not occur. Although the text violates the statistics of English, it violates neither grammar nor sense [*see illustration on page 36*].

Another part of Chomsky's argument was that neither the Markoff process nor any existing grammar gave simple, sensible explanations for many obvious features of English, including the passive voice. To this end Chomsky proposed a new grammatical concept: the transformational grammar.

Chomsky's work was important in two ways. It led a number of linguists, Yngve among them, to try to produce transformational grammars of English. This work produced grammars that became larger and larger and less and less intuitive; moreover, none of the grammars produced could generate all grammatical sequences and no ungrammatical sequences.

Another outcome of Chomsky's work was to inspire certain psychologists,



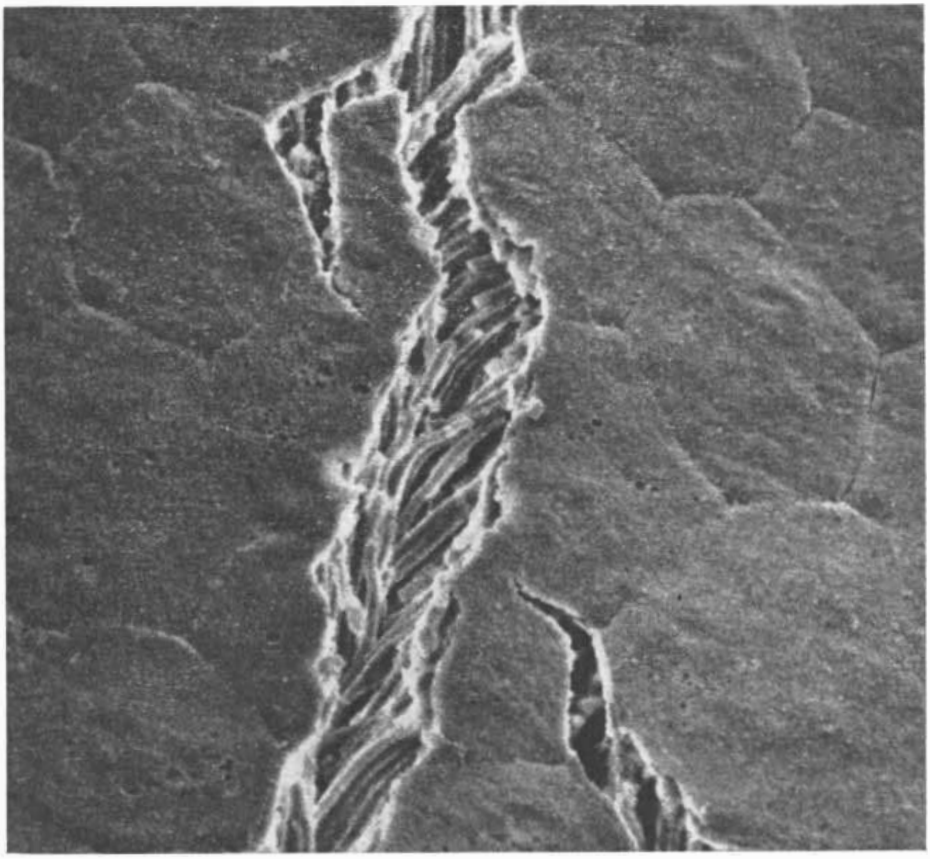
CUBIST PORTRAIT of John R. Pierce, the author of this article, was made by Leon D. Harmon of the Bell Telephone Laboratories as part of a computer experiment designed to determine the least amount of visual information a picture can contain and still be recognizable. The picture is divided into about 200 squares, with each square rendered evenly in one of 16 intensities of gray. For best results the portrait should be viewed from a distance of 15 feet or more; jiggling the picture, squinting or removing one's eyeglasses also helps. Such studies of the information content of a visual image may be useful in devising future systems for storing, transmitting and displaying pictures with the aid of computers.

notably George A. Miller, then at Harvard, to do experimental work on human response to language. At first this line of inquiry seemed very fruitful. For one thing, response to the active voice appeared to be quicker than response to the passive voice, a finding consistent with the view that the passive voice involves an additional transformation. As such work has proceeded it has become complicated and unclear in implication, except for one thing: the importance of meaning in communication [see "Verbal Communication," by Roman Jakobson, page 72].

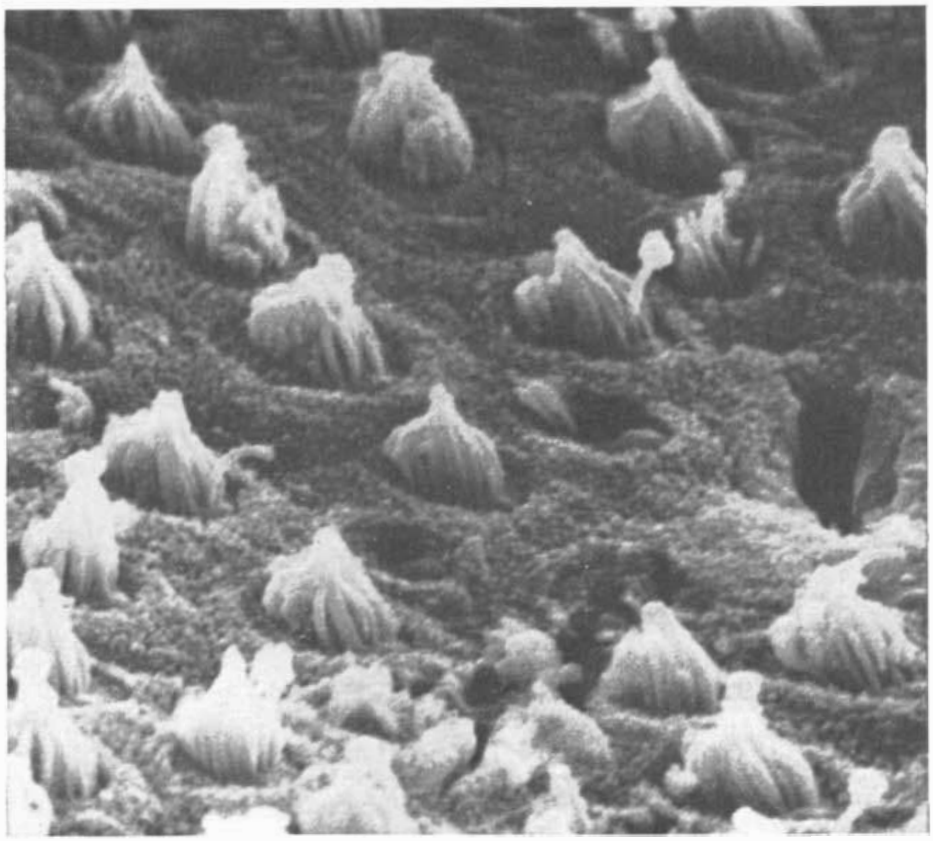
Remember that Chomsky proposed as a criterion for a sentence's being grammatical that it be "acceptable to a native speaker." When in fact naïve native speakers are asked whether or not a sentence is grammatical, they frequently reject it as being ungrammatical unless it makes sense to them. Conversely, ingenious people will spontaneously and gleefully invent tortured circumstances in which a seemingly meaningless or ungrammatical sentence will actually be acceptable to a native speaker. We are inclined to reject "I is a boy," but what is our reaction to be if we are visiting a school in which all the children are assigned pronouns rather than being called by their names?

Indeed, whether or not a sentence is grammatical or meaningful seems to depend ultimately on the ingenuity of the person who puzzles over it. Even then we are left with Weaver's exception: "Similarly, anyone would agree that the probability is low for such a sequence of words as 'Constantinople fishing nasty pink.' Incidentally, it is low, but not zero; for it is perfectly possible to think of a passage in which one sentence closes with 'Constantinople fishing,' and the next begins with 'Nasty pink.' And we might observe in passing that the unlikely four-word sequence under discussion has occurred in a single good English sentence, namely the one above."

Weaver therefore stresses meaning and effectiveness in communication. We find this search for meaning and effect outside the laboratory both in the myths and magic of antiquity and in our own daily experience. We find meaning in text or speech even when the text is corrupt or the speech scarcely audible. William James had observed this truth in 1899: "When we listen to a person speaking or read a page of print, much of what we think we see or hear is supplied from our memory. We overlook misprints, imagining the right letters, though we see the wrong ones; and how



VISUAL-INFORMATION RECEPTORS are represented in this scanning electron micrograph by the outer rod segments seen through a tear in the membrane at the back surface of a rabbit's retina. The micrograph was made by Thomas F. Budinger and Thea Scott of the Lawrence Berkeley Laboratory. The magnification is approximately 4,000 diameters.



AUDITORY-INFORMATION RECEPTORS are shown enlarged some 6,000 diameters in this scanning electron micrograph of the ciliary tufts of hair cells in the sacculus, or inner ear, of a frog. The micrograph was made by James Pawley of the University of California at Berkeley working with a sample prepared by Edwin R. Lewis in his laboratory at Berkeley.

little we actually hear, when we listen to speech, we realize when we go to a foreign theatre; for there what troubles us is not so much that we cannot understand what the actors say as that we cannot hear their words. The fact is that we hear quite as little under similar conditions at home, only our mind, being fuller of English verbal associations, supplies the requisite material for comprehension upon a much slighter auditory hint."

This passage from James gives us a strong clue to understanding where the meaning of language really resides. It is useless to seek the meaning or utility of a book between its covers, or the intent or effect of a speech in the sounds that are uttered. A textbook on physics or mathematics exists in the context of the physics and mathematics of its time. It is not a complete exposition of the physics or mathematics it is intended to teach. Such a text is addressed to a person who already knows a language, something about the world and something about physics and mathematics. It is intended to enable him to learn, understand and use knowledge, skills and insights that the author himself has acquired. Taken out of its environment of language, such a textbook would be completely unintelligible. Taken out of its environment of physics or mathematics, such a textbook might be interpreted symbolically, construed as magic or dismissed as boring nonsense.

Our everyday communication has meaning in a much more restricted context. An order on a battlefield communicates only to a soldier who knows the situation, and the situation cannot be re-created by an examination of the words uttered. Phrases passed back and forth in a discussion may earn John Smith a raise or cost him his job, but the phrases have meaning only with respect to what those who are discussing Smith already know about him. Communication can take place only between people with a common aim, a common problem, a common curiosity, a common interest; in other words, something in common that is meaningful and important or fascinating to both. The process of communication is not one of imparting entire areas of knowledge or of drastically changing views. That is the process of education or training, which makes use of communication but goes far beyond communication as we commonly construe it. Communication in everyday use is a process of adjusting understandings and attitudes, of making them congruent or of ascertaining how and where they agree or disagree. A common language is of extreme advantage in our efforts to communicate, but it is not as important as a common interest and some degree of common understanding.

Yet if we had everything, or almost everything, in common, no communication, or very little communication, would suffice. That is the case with certain animals, such as bees [see "Animal Communication," by Edward O. Wilson, page 52]. The need for communication arises because something unguessable must be imparted concerning our understanding or actions. A little must be added to what we already know or as a basis for modifying what we would otherwise do. It is this element of the unguessable that Shannon measures as entropy. And it is the unguessable, the surprising, that is an essential part of communication, as opposed to the mere repetition of gestures, incantations or prayers.

Meaning can exist only through what we have in common in our lives, minds and language. It is concerning what we share that communication takes place. We cannot be certain that reassurance will be offered, and we are upset if it is not. We are excited by a new discovery or by a tidbit of gossip about someone we love or hate. We spring to a task we understand and feel impelled to undertake. And, as I have observed, we con-

XXIX

GADSBY WAS WALKING back from a visit down in Branton Hills' manufacturing district on a Saturday night. A busy day's traffic had had its noisy run; and with not many folks in sight, His Honor got along without having to stop to grasp a hand, or talk; for a Mayor out of City Hall is a shining mark for any politician. And so, coming to Broadway, a booming bass drum and sounds of singing, told of a small Salvation Army unit carrying on amidst Broadway's night shopping crowds. Gadsby, walking toward that group, saw a young girl, back towards him, just finishing a long, soulful oration, saying:—

". . .and I can say this to you, for I know what I am talking about; for I was brought up *in a pool of liquor!!*"

As that army group was starting to march on, with this girl turning towards Gadsby, His Honor had to gasp, astonishingly:—

"Why! Mary Antor!!"

"Oh! If it isn't Mayor Gadsby! I don't run across you much, now-a-days. How is Lady Gadsby holding up during this awful war?"

[201]

IMPROBABLE TEXT, represented by this page copied from the 1939 novel *Gadsby*, by Ernest Vincent Wright, violates the statistics of English, although it violates neither grammar nor sense. Wright's entire novel of more than 50,000 words was written without a single word containing the letter *e*. This extraordinary counterexample serves to symbolize the difficulties associated with a purely statistical approach to the analysis of language. Such problems came into prominence in the course of early attempts at computer translation, leading certain linguistic theorists, such as Noam Chomsky of the Massachusetts Institute of Technology, to undertake a reexamination of syntax in linguistic communication.

tinually search for meaning, whether or not meaning is there.

I believe it is a mixture of surprise and the search for meaning in a familiar context—the English language—that lends charm to Shannon's statistical words *grocid, pondenome, deamy*. They are so like English that we wonder what they mean, or perhaps we feel that we sense some elusive meaning or connotation. I think that it is our straining toward some such extraordinary context or meaning that gives charm to computer-produced "poems" such as those of Marie Borroff:

The river
Winks
And I am ravished.

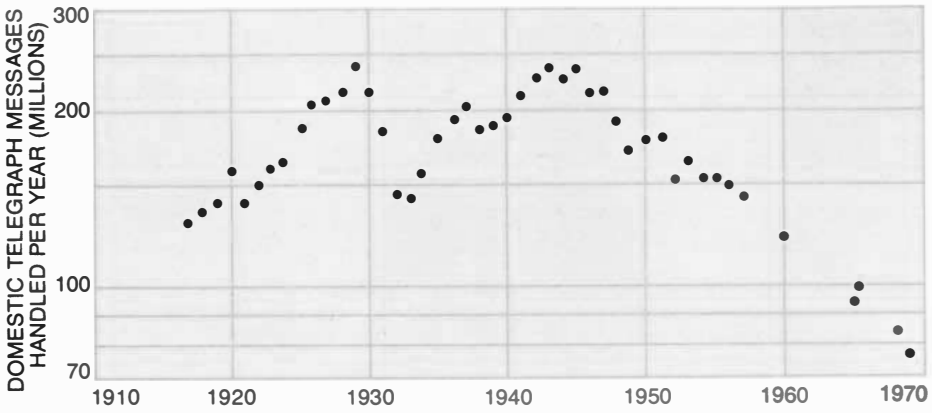
Dangerously, intensely, the music
Sins and brightens
And I am woven.

These poems are not so much out of the world as enticingly on the fringes of it.

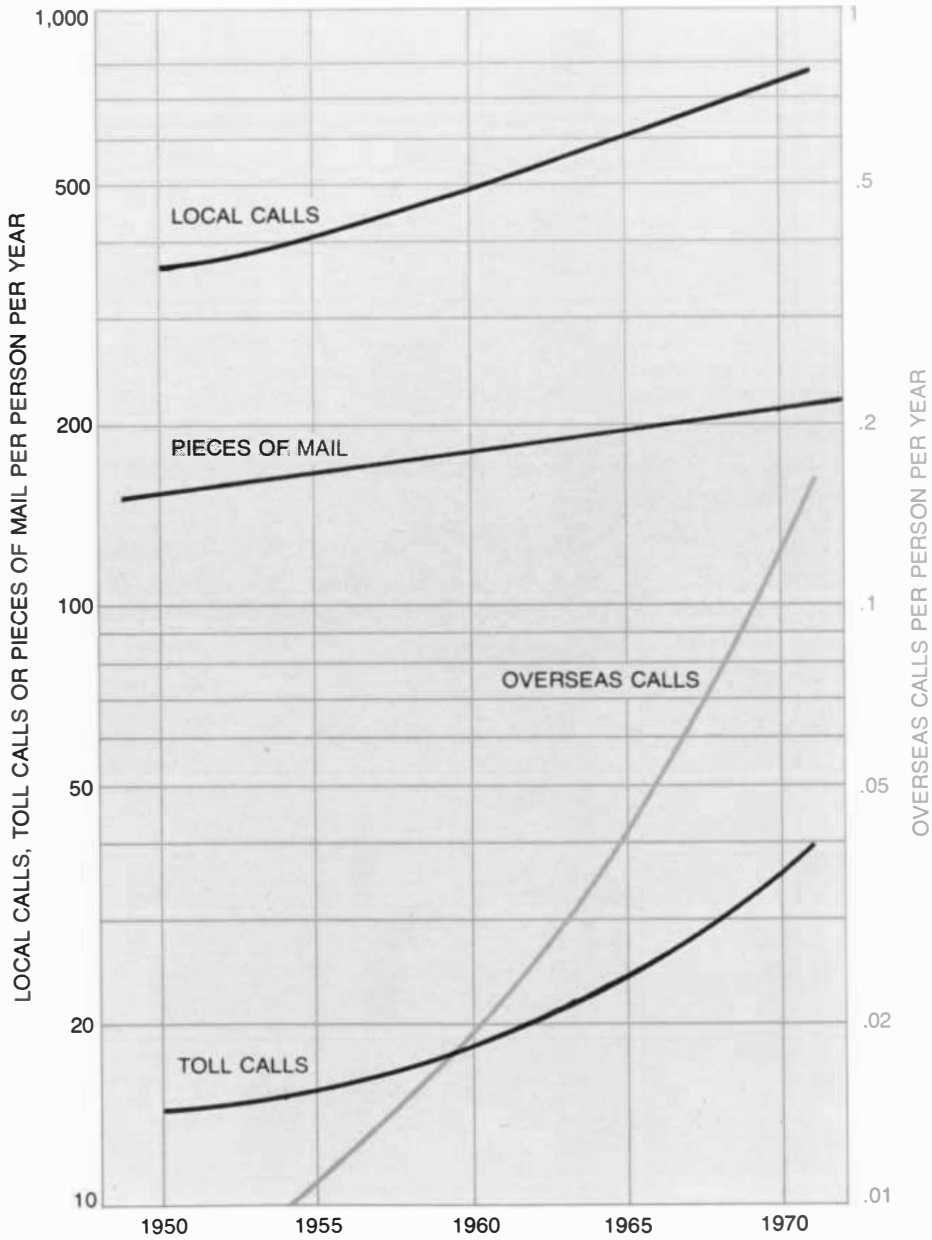
We are challenged by what seems almost within our comprehension, but we reject or are bored with whatever completely eludes our grasp. Using computer-generated patterns, Bela Julesz of the Bell Telephone Laboratories has shown that a given degree of order or redundancy (in the sense of information theory) can be detectable or undetectable to the eye, trained or untrained. Here is one point of departure between information theory and problems of human communication.

The information theorist asks: What is a general measure of order, or rather of disorder, in a message source, and how can I take advantage of the order that is there in transmitting messages from that source efficiently? To do this, however, one must adapt the communication equipment to the order that lies in the source. Our eyes, ears and brain, adapted as they may have been through evolution, are with us throughout our lives. We can make use of order only if we can perceive it. Some order we can learn to perceive; some must escape our senses, to be detected only through statistical analysis.

Many artists and musicians who have been inspired by information theory have sought to produce works with an optimum combination of order and randomness. Such a criterion antedates information theory. Beethoven is said to have declared that in music everything must be at once surprising and expected. That is appealing. If too little is surprising, we are bored; if too little is expect-



RISE AND FALL of a form of communication, the telegraph, is traced in this graph of the total number of domestic telegraph messages handled in the U.S. from 1917 to 1970.



ACCELERATING USE of two other forms of communication, the postal service and the telephone, in recent years has contributed to the decline of telegraphy. The rate of increase for pieces of mail per person is currently about 3.5 percent per year, for local telephone calls per person about 5 percent per year, for toll telephone calls per person about 10 percent per year and for overseas telephone calls per person about 25 percent per year.

ed, we are lost. Communication is possible only through a degree of novelty in a context that is familiar.

Music communicates at once by reassurance and by surprise, but we can be neither reassured nor surprised by what passes unnoticed. Sir Donald Tovey, the British composer and writer, characterized certain contrapuntal devices as "for the eye only" and so implied that they must go unheard and unappreciated by the listener.

Order undetected is order in vain. One contemporary Canadian composer, Gerald Strang, has said that much random music and much totally organized music sound alike: uniformly gray. This would indeed be the consequence of an order undetectable by the ear and brain.

As to what is perceivable order and what is not, there will be long arguments. Some will say that the occurrence of the diatonic musical scale in unrelated cultures argues that it is physically or psychologically suited to man, whereas the only basis for 12-tone music is the fact that the piano has 12 black and white keys per octave. Others will argue that what we expect and what surprises us in older music is entirely cultural; that with sufficient training and effort on the part of the listener today's gray music will come to shimmer with color and startle with surprise, intellectual if not acoustical. It is plausible that what has moved many men may move others; it is less plausible that men will necessarily come to be moved by what has moved no one.

So far in this article I have associated communication entirely with man and communication among men. Another kind of communication is growing up around us: communication among machines. Here we are back to the process of devising, understanding and improving tools. We do not care about the working conditions or interests of computers. In the end we do not care how our credit-card transactions are processed as long as the process is accurate, cheap and prompt. What we do care about is providing a simple, easy-to-use, compact, reliable terminal by means of which a man can send messages to a machine and receive messages from it.

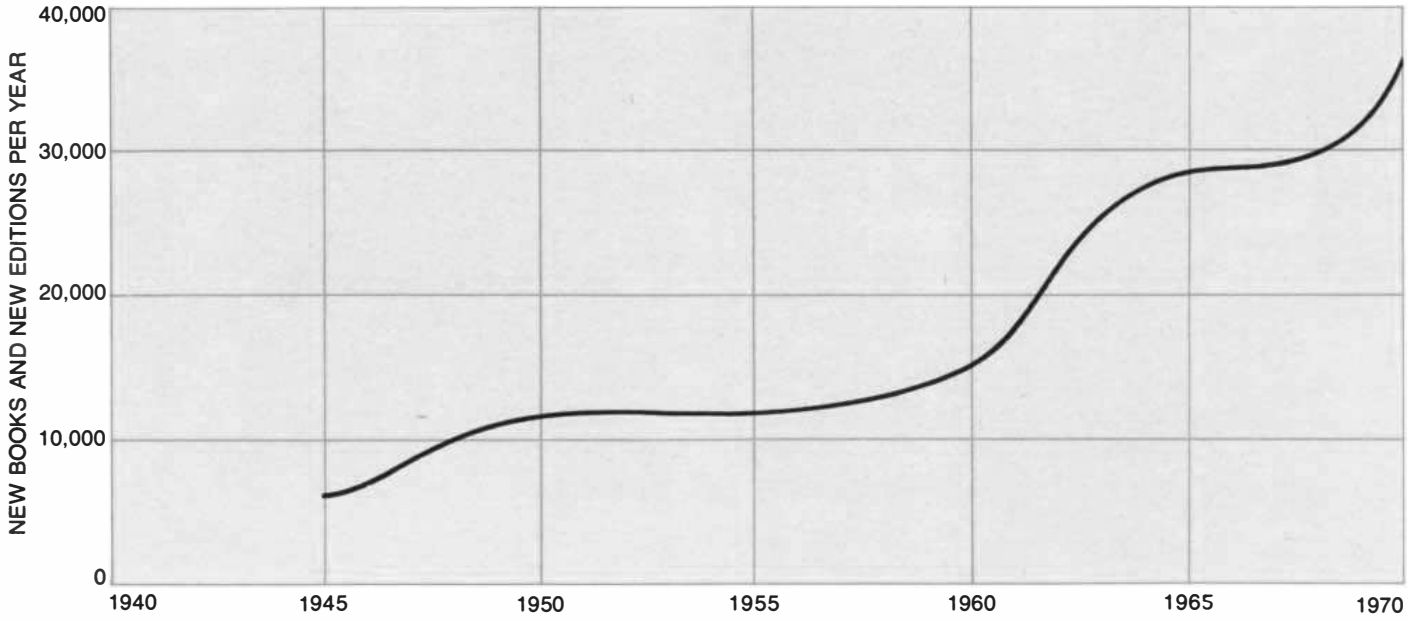
It seems ridiculous to speak a credit-card number into a telephone and have the computer operator key the number into the machine and relay the machine's yes or no answer by voice. It *is* ridiculous, and people are working on machines to read credit cards and communicate with a distant computer directly.

All of us look toward communication with distant computers from the home or the office, but as yet there are no adequate terminals. Teletypewriters are large, clanking and costly. Cathode ray terminals are large, limited and costly. The problem is that we have no cheap and adequate means for display. Keyboards are compact, reliable and easy to use. I for one would rather command a computer through a keyboard than talk to it, even if that science-fiction dream were possible.

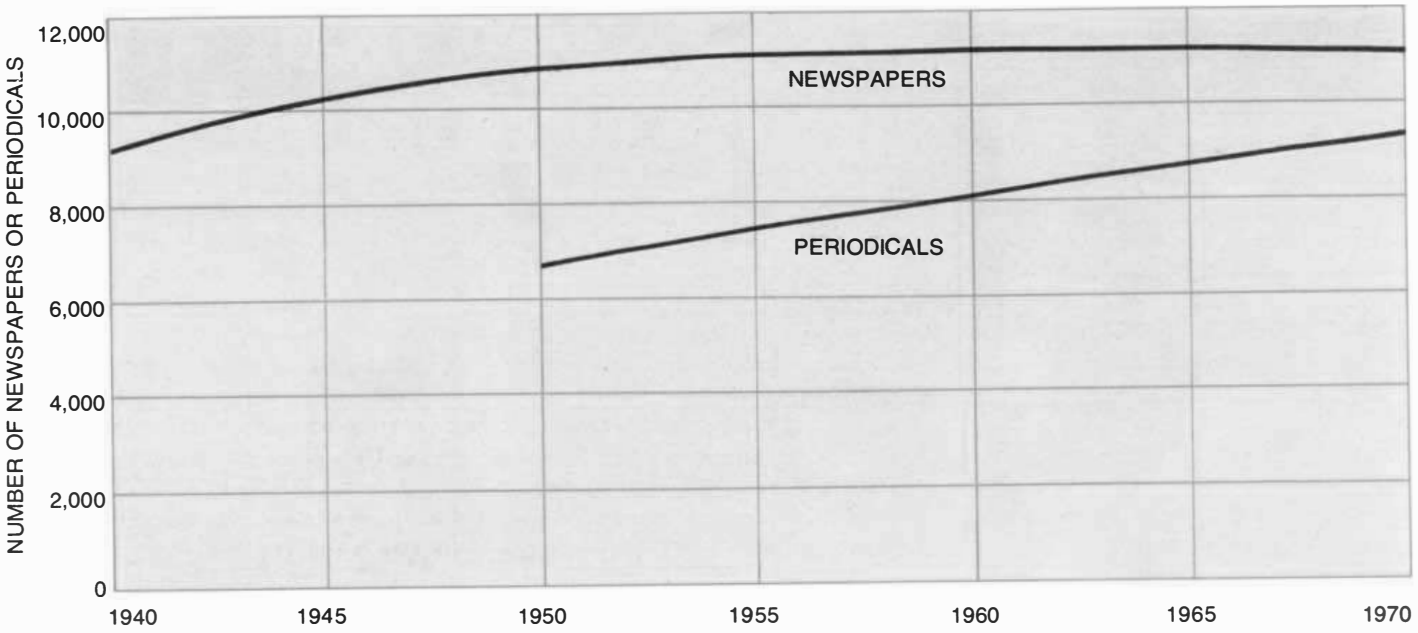
The widespread use of computers is held up by lack of cheap, compact, reliable terminals, and by other things as well. The field of data communication and interacting computer systems is powerful and fascinating. It calls into play not only communication theory but also the construction of artificial languages, complete with grammars and the devising of computer programs of great complexity. Such communication is a growing part of our world, but it is remote from the average user of communication, who sees and cares to see only the terminals by means of which he uses such computer systems. As the computer and terminal arts advance, we shall have all kinds of new services in our homes, whether for consulting advertisements, purchasing, making reservations, learning algebra or learning Japanese. All of this and more will come, but when it will come is hard to judge [see "Communication Terminals," by Ernest R. Kretzmer, page 130].

Whatever one may say about communication among machines, human communication takes place within a community of interest made up of human beings. Within that community people think and act, and they communicate in moving others toward or away from what they regard as appropriate thoughts and actions. In terms of information theory only certain messages among all possible messages occur in communication within a community of interest, because only certain messages are appropriate, make sense and will be understood.

In a simple society, an isolated band or a village with a subsistence economy, a community of limited size and complexity provides a community of interest common to all. Speech supplies ade-



IRREGULAR UPWARD TREND characterizes this plot of the number of new books and new editions of old books issued in the U.S. each year from 1945 to 1970. An initial rise after the end of World War II was followed by a plateau (perhaps associated with a period of postwar practicality and conformism), which in turn gave way to a wavering but very steep rise beginning in about 1960.



INTERESTING CONTRAST is evident in this graph, which shows that the number of periodicals published in the U.S. over the period 1950–1970 has increased steadily, whereas the number of newspapers published over the same period has become fairly stable.

quate communication. The family or the clan may be a subsidiary community of interest. Other places, other people and other times must somehow be taken into account in myth and custom. Nonetheless, to a degree all of life (that is, all that is noted) is accessible and intelligible to all members of the community.

Our world has far outgrown the reach of the voice or the comprehension of any one mind. It is divided into countless communities of interest. Increasingly these communities are intellectual rather than geographical. A physicist or a mathematician or a biologist may have more in common with a colleague in a foreign land than he does with his next-door neighbor.

Our multiple communities of interest and the institutions that serve them overlap. A mathematician may be interested in the stock market and in riding unicycles. An engineer may be interested in spectator sports, skiing and music. A science-fiction writer may be interested in local politics. That each man is a member of many communities of interest makes them no less real.

Clearly such communities of interest could not exist without adequate communication. I shall not argue that advances in communication and travel have brought these communities of interest into being, or that conversely wide-ranging interests have stimulated the technologies of travel and communication. What is clear is that communication plays a complex role in a complex way of life. In so serving us modes of communication interact with the people they serve in many ways [see "Communication and Social Environment," by George Gerbner, page 152].

Some forms of communication serve many communities of interest, ranging from the individual and the family to large business and cultural organizations. The postal service, the telegraph and the telephone are among these forms. The telegraph provides an interesting example of the rise and fall of a form of communication. When one plots the domestic telegraph messages handled from 1917 to 1968, one finds a faltering peak from 1930 to 1935 [*see top illustration on page 37*]. Anyone who has sent or received telegrams can read a variety of economic and social observations into these data. On the one hand one sees competition from the telephone, through direct distance dialing and decreasing long-distance rates. On the other hand one sees that a dispersal of population into suburbia and rising labor costs have combined to make the physical delivery of telegrams uneconomic. Those with long memories may recall the knock of the telegraph boy at the door. They may even recall office switches that would summon telegraph boys to take messages. Such services have vanished, and Western Union is seeking a new mode of life.

Mails and telephony, in contrast, are still on the increase, with the telephone winning out [*see bottom illustration on page 37*]. There are more local calls per person than pieces of mail per person, and the rate of increase is faster. Furthermore, toll calls increase twice as fast as local calls and overseas calls increase more than twice as fast as toll calls. In such statistics we see a society in which human relations and business transactions both have a shorter time scale. Life has become less leisurely, less planned, more immediate. The increases in toll calls and overseas calls also tell us that communities of interest are becoming more far-flung.

These increases in part reflect advances in technology that have made such calls cheaper and better. Quality is important to the use and success of communications. Overseas calls increased rapidly after 1954, when the first undersea cable made overseas calls more intelligible and useful than they had been in the days of shortwave radio. Cost is equally important. Surely a reduction in the cost of toll calls, and particularly of calls during certain hours, has stimulated such calling.

Although a decrease in cost can stimulate the use of communications, too high a cost can result in no use whatever. Invitations are no longer carried by footmen. And, technological marvel though it is, the Bell System's Picturephone service seems unlikely to sweep the country. The cost is greater than people care to pay, particularly for long-distance calls. So it seems to be with many ambitiously proposed communication systems. The cost is more than the traffic will bear. In time videotelephone and home communication centers will be available to all, but only when radical advances in technology bring the cost down. That time will not be tomorrow.

Telegrams, the postal service and the telephone serve almost all communities

of interest. Some modes of communication serve large communities of interest only. Books are among these. Nothing is more diverse than books. With rare exceptions (the Bible is among them) each book reaches a small fraction of the total population. Yet a successful book may reach a large fraction of those deeply interested in a particular area or subject, be it yoga, tennis, the stock market or general relativity. In the last instance a successful book can blanket the real community of interest with a few thousand copies.

A plot of the number of new books and new editions of old books issued each year from 1945 to 1970 reveals that there was an initial rise after the war and then a plateau. We can associate the plateau, if we wish, with postwar practicality and conformism [*see illustration on page 38*]. About 1960 a wavering but very steep rise set in. Does this rise reflect an increasing diversity and a growing number of communities of interest? Or does it reflect a reduction of cost and an increasing number of outlets during the paperback revolution? I am sure that it reflects both, and that both are a part of the interaction of communication and society.

A book can serve a rather narrow community of interest, for example the worldwide community of specialists in some field of science. In general periodical publications must have a larger readership in order to survive. Nonetheless, the number of periodicals published over the period 1950–1970 has increased steadily [*see illustration on preceding page*]. This increase reflects a growth in communities of interest of substantial size, including the community of interest that is served by this magazine.

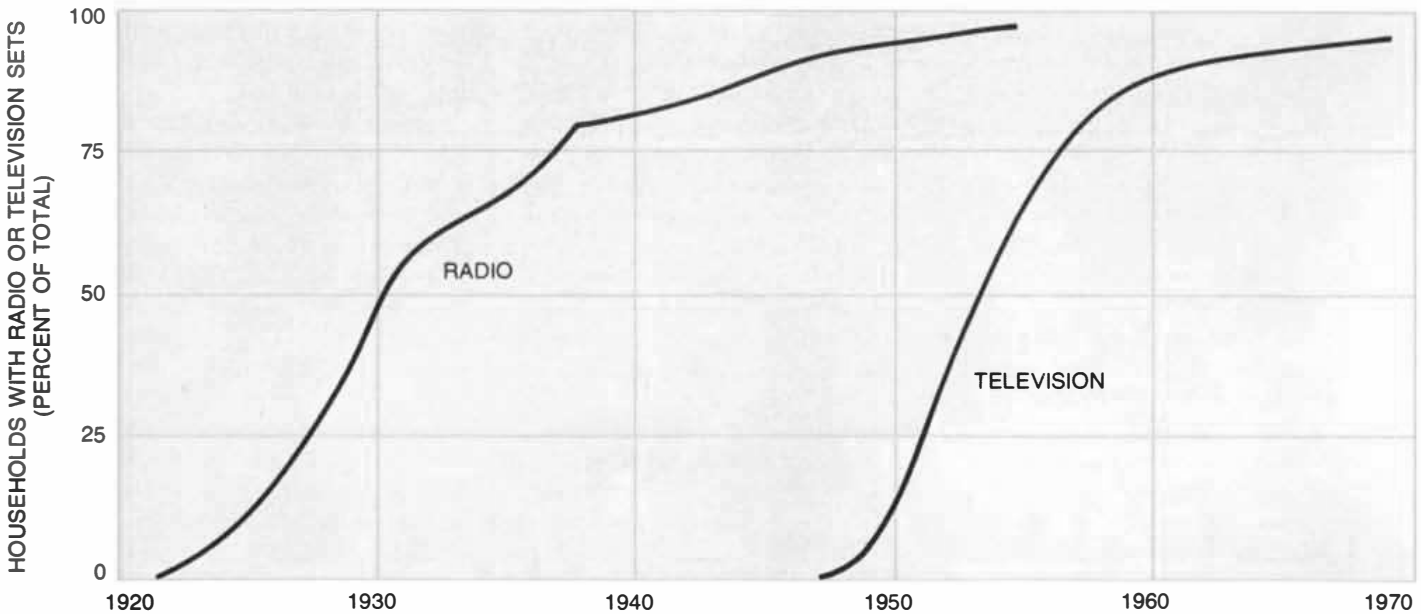
I believe that such statistics actually underestimate the true number of periodical publications, and that they omit many that serve very real communities of interest. Particularly in technology and business, there are a large number of highly specialized periodical publications: monthly, quarterly or yearly. They are directed to subjects as special as digests of commercially available computer hardware and analyses of the financial condition and prospects of certain companies. The subscription price for some is extremely high; this factor seems to show that they serve particular communities of interest better than more general technical or financial journals. Other highly specialized and probably uncounted periodicals include the mimeographed science-fiction fan magazines called "fanzines" and endless club and society bulletins and the like. All serve real communities of interest.

It is interesting to note that whereas the number of periodicals is rising, the number of newspapers is static. I think that here too one can read meaning into statistics. As we progress from the mails and the telephone through books, through periodicals and on to newspapers we are considering successively media that necessarily serve larger and larger communities of interest. With the newspaper we have arrived at what survives of the geographical and the national communities of interest. Newspapers must appeal to such interests as we all have in common because we live in a particular community, state or nation.

What is true of newspapers is also true of radio and television [*see illustrations below*]. Here we see that whereas virtually every home has a radio and a television set, the number of stations is still rising somewhat. With the advent of the communication satellite, television has become a truly international medium. President Nixon's trips to China and the U.S.S.R. and the astronauts' trip to the moon have been hit shows. With the growth in diversity, however, the geographical, the national and indeed the international communities of interest have come to occupy an equivocal place in our lives. Mass communications have come to have an uncertain role in the functioning of society. It can be argued that mass communications are not effective eyes and ears on the world, and that they do not ensure popular participation in government.

Here I come back to Wiener's *Cybernetics*, to which I have scarcely referred since I mentioned it at the beginning of this article. Unlike Shannon's "The Mathematical Theory of Communication," *Cybernetics* does not expound a novel, well-defined and well-implemented body of theory. Rather it is a discussion, partly mathematical and partly popular, of the relation between certain concepts and man and his world.

One prime concept expounded by Wiener is homeostasis: the functioning of an organism or a system so as to correct for adverse disturbances. Homeostasis involves two processes: the detection of deviation from the desired state, and negative feedback, by which the discrepancy between the desired state and the present observed state is cor-



ASCENDANCY OF MASS COMMUNICATIONS is reflected in the graphs on these two pages, which show that whereas virtually every home in the U.S. now has both a radio and a television set (*left*), the number of radio and television stations is still rising

rected. The process of homeostasis may fail in many ways.

For the overall process to function, we must satisfactorily sense that some correction needs to be made. Beyond that, however, negative feedback may itself result in instability. This happens when there is too much negative feedback, or when it acts too quickly in a system in which some responses are necessarily slow. The normal human being can observe the fallibilities of feedback by trying to carry a shallow pan full of water without spilling it. He had best keep his eyes off the pan as he walks along, however. Efforts guided by the eye ordinarily heighten rather than reduce the sloshing of the water.

Wiener observes that "small, closely knit communities have a very considerable measure of homeostasis; and this, whether they are highly literate communities in a civilized country, or villages of primitive savages. Strange and even repugnant as the customs of many barbarians may seem to us, they generally have a very definite homeostatic value, which it is part of the function of anthropologists to interpret. It is only in the large community, where the Lords of Things as They Are protect themselves from hunger by wealth, from public opinion by privacy and anonymity, from private criticism by the laws of libel and the possession of the means of communication, that ruthlessness can reach its most sublime levels. Of all of these antihomeostatic factors in society, the control of the means of communication is the most effective and most important."

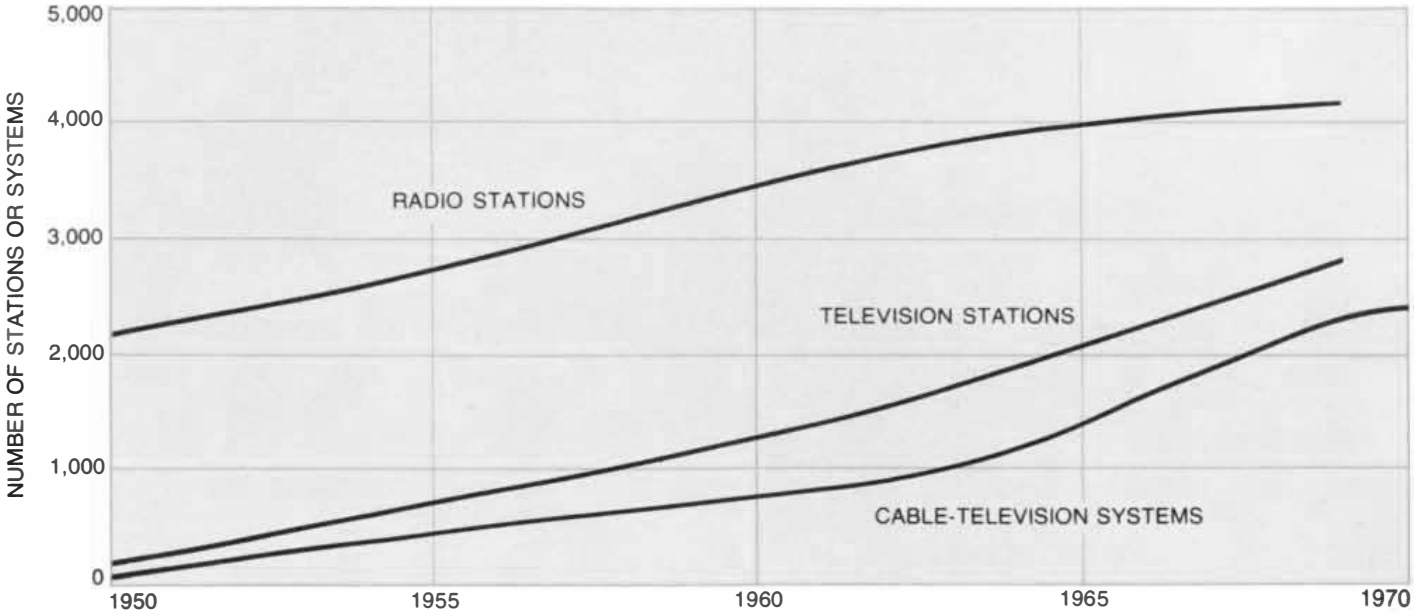
No doubt greed, self-interest and callousness do account for failures of communication in our overall community of interest. We may also observe, however, that the world in which we live and which affects our daily lives has become overwhelmingly complex. We cannot possibly understand it in the sense that we might understand a small, closely knit community. If we do not disregard the larger world, we must perceive it as it is represented by the media of mass communication. Is this, however, a real world, or is it a myth that stands in the place of something we cannot possibly understand?

It seems common that those with special knowledge, be it of science or publishing, distrust mass-media presentations of their own fields while accepting the pictures the media present of other fields. Even in the large a civil war in Nigeria attracted notice and aroused passion, whereas one in the Sudan went unnoticed and left us cold. Can the mass media present a useful picture of an overall community of interest? To what degree does such a community of interest exist? And whose interests are taken into account?

Whatever may be the reality of the overall community of interest people observe, they do react to it strongly and sometimes violently. Even if this reaction were a reaction to the true state of affairs, it would not necessarily result in a return to the desired state, whatever that might be. I think all societies perceive this difficulty of perception and reaction. In totalitarian societies great efforts are made to narrow and control the channels of communication. In open societies the channels of communication are open, but constraints such as due process and checks and balances are put on the speed and magnitude of reaction. Yet, as society becomes ever larger and more complex, the problem of communication and control in the overall community of interest becomes progressively more difficult [see "Communication and Freedom of Expression," by Thomas I. Emerson, page 163].

At times governments show a public awareness of this. One response is to try to make society simpler and more uniform through centralization and drastic restrictive legislation concerning whatever is deemed to be antisocial or unfair or simply unpopular. Another response is to try to make communication and control operate meaningfully and effectively by pushing power toward communities of interest, whether these are intellectual, technological or geographical in the sense that regions, states and cities are.

Long before we took deliberate steps in this latter direction, men's communities of interest had somehow multiplied, differentiated themselves and had in many cases broken their geographical bonds. The amount of communication we use, the distances over which we communicate and the increasing diversity of books and periodicals show this clearly. Still, geography governs some aspects of our lives. However universal our understanding of science or our enjoyment of music may be, we prefer stoves in the Arctic and air conditioners in the Tropics. The world that communication and transportation have built is exceedingly complex and very difficult to govern wisely.



somewhat (*right*). The graphs are derived mainly from two sources: *The American Almanac*, which is published by Grosset & Dunlap in 1972, and *Historical Statistics of the United States: Colonial Times to 1957*, published by the U.S. Department of Commerce.